Modelling fishing location choice within mixed fisheries: English North Sea beam trawlers in 2000 and 2001

Trevor Hutton, Simon Mardle, Sean Pascoe, and Robin A. Clark

Numerous studies have proposed methodologies to model fisher behaviour with the aim of predicting the outcomes of decision-making on board a fishing vessel. Both short- and long-term processes (e.g. investment) impact fleet dynamics. The proposed structure of the models has tended to depend upon the nature of the fishery and the control variables (technical restrictions, quotas, effort control, and/or closed areas). For example, within the context of multi-stock, multi-fleet fisheries (mixed fisheries), a skipper will allocate effort (as input to the production process) to harvest a range of species. Spatial complexity is normally excluded in models of behaviour. In this paper, two spatial analyses are presented for modelling location choice: an analysis based on a random utility model (RUM), and a simplified simulation model of individual vessels that depends on the results of the RUM. These models are applied to the English beam-trawl fleet operating in the North Sea in 2000. The results from the RUM indicate that the number of trips, the average trip length, and the average effort in each ICES rectangle are significant variables affecting location choice, in addition to catch rate for the previous year (1999), weighted by value. The last result is used as an assumption in a simulation model of fishing effort, i.e. fishers make decisions on spatial location of operation on the basis of past catch rates. The simulation model is used to predict the distribution of the same fleet for one month during the temporary closure in the North Sea in 2001. The predicted values for effort relate well to the fishing patterns observed.

Introduction

Many methods have been applied to model fisher behaviour in terms of choice of fishing grounds and/or target species (e.g. Hilborn and Ledbetter, 1979; Bockstael and Opaluch, 1983; Mangel and Plant, 1985; Eales and Wilen, 1986; Wilson, 1990; Dreyfus-Leon, 1999; Allen, 2000a, b; Babcock and Pikitch, 2000; Smith, 2002; Wilen et al., 2002). The models are proposed as a means of predicting the outcome of decision-making on board a fishing vessel, although many may look at the problem from an aggregated fleet perspective. Where such an individual-based analysis has been undertaken, it is primarily short-term behaviour that is modelled. However, fleet dynamics are the result of both short- and long-term decision processes (e.g. investment, and other economic behavioural characteristics), and the accompanying outcomes of the decisions made by individual fishers. Wilen (1979) suggested that modelling behaviour is important for predicting, understanding, and designing efficient regulatory programmes.
Within the context of multi-stock, multi-fleet fisheries (mixed fisheries), a skipper will allocate effort (as an input to the production process) in order to harvest a range of species, whereas regulations tend to apply to a single-species total allowable catch (TAC) system. Spatial complexity is also normally excluded. The distribution of fishing effort is assumed to either move towards areas of best catch (Maury and Gascuel, 1999) or greatest catch rate, which then may be modified for distance from port (Sampson, 1991), or greatest profit (Bockstael and Opaluch, 1983; Chakravorty and Nemato, 2001).

The structure of the models in the literature depends on the nature of the fishery (state or structural variables), and the control (or choice) variables. Choice, or behavioural modelling of the effects of quota restrictions, effort control, and/or closed areas can then be considered. Hilborn (1985) classified different behaviours in order to consider alternative modelling approaches. These were:

(i) investment,
(ii) technological change,
(iii) location choice, and
(iv) discarding.

Here, we concentrate on item (iii) (location choice), because it applies to short-term dynamics. Within our application of models for location choice, two methods (a random utility model, RUM, and a simulation model of individual vessels) are applied to a case study that provides insight into the assumptions, strengths, and weaknesses of each approach, as well as the data requirements.

**Methodology**

Descriptive techniques can be used to characterize fishing tactics on a spatial scale, using location choice as a key variable (Pelletier and Ferraris, 2000). However, such methods do not provide an indication of the underlying choices. The significance of explanatory variables that can explain the patterns of distribution observed is typically not assessed. Fishing is an economic activity, so spatial patterns of fishing effort are largely driven by expected economic returns (Gordon, 1954), as shown by Hilborn and Ledbetter (1979) in an empirical study of a purse-seine fleet. However, Gordon’s model also assumes that profit rates would equalize over areas fished, thus not taking account of differences in fish density. As noted by Holland and Sutinen (2000), such homogenization is not always a valid assumption, because perfect information is rarely available. As such, traditional practices reduce uncertainty in terms of fishers having expected gains, and fishing units will often return to “their fishing grounds”.

Expected economic returns are determined not only by what is landed (the revenue, so fishing units will seek out high catch rates), but also by the costs associated with the fishing trip. Costs also increase as steaming time increases. Predicting the distribution of a fishing fleet can be complex when the vessels use various ports, and they are landing more than one species. Allen and McGlade (1986) proposed a model based on the probability of selecting alternative fishing grounds, which in turn was based on the utility (expected net rate of return) of each fishing ground. Alternatively, vessels could redistribute their effort over open areas (assuming that some areas were closed), based on the assumption that they would fish on a fishing ground where other similarly powered vessels operated. In a different approach, Walters and Bonfil (1999) made use of a profit maximization function in presenting a “gravity” model for the distribution of effort among grounds. The “gravity” model predicts the share of effort to each ground based on expected economic variables, i.e. how profitable a fishing ground is going to be, based on a function that includes fish availability and cost factors. Furthermore, the assumption could be made that vessels will allocate effort according to Ideal Free Distribution theory, which predicts that vessel density is proportional to resource abundance (see references in Gillis et al., 1993, and Gillis, 2003, and the application in Rijnsdorp et al., 2000b). If we assume that catch per unit effort (cpue) is proportional to abundance, then vessels would gravitate towards areas where the catch rate is highest. Rijnsdorp et al. (2000a) showed that this is indeed the case, vessels depleting areas until the catch rates dropped.

Fishing vessels confronted with a closed area which they regularly or sometimes fish will move (relocate or be displaced) to other areas. Rijnsdorp et al. (2001) found that vessels fished at the perimeter (border) of a closed area, a phenomenon that Maury and Gascuel (1999) were able to simulate in a spatial bioeconomic model. The assumption here is that an area is closed to protect a species that is normally abundant there, so catch rates will generally be highest in what is now the closed area. Holland (2000) simulated the effects of closed areas on fish populations within a dynamic bioeconomic model, which includes a fleet dynamics submodel based on location choice behaviour. This submodel is based on a discrete choice random utility model (Holland and Sutinen, 1999), which explains the observed location choices, and can predict them. Holland and Sutinen considered individual vessels, using a RUM for location choice of 400 heterogeneous trawlers (trip data), including lagged average revenue rates for alternatives, as well as past behaviour, for predicting location choice and species mix. Although the model is based on explanatory variables at the level of the individual vessel, it can predict aggregate effort levels in alternative fishing locations. Such explanatory variables relate not only to profit maximization, but also to factors such as tradition/habit (i.e. return to the same fishing grounds). In another application of RUMs to fisheries, Wilen et al. (2002) considered the California red sea urchin dive fishery, in which a diver selects a home port at the beginning of a season, chooses to participate on the basis of weather, prices, expected abundance, diver traits, and processor...
commitments, then decides on both dive locations and diving hours.

In order to investigate similar characteristics (as those observed by Holland and Sutinen, 1999) in the English North Sea beam-trawl fleet, two approaches are presented here: a location choice model based on a RUM, and a simulation model of fishing effort that assumes that vessels will redistribute effort from closed areas to open areas on the basis of the results of the RUM.

Location choice and the random utility model
Several studies in fisheries now exist that implement random utility methodology for predicting individual fisheries and location choice (e.g. Bockstael and Opaluch, 1983; Eales and Wilen, 1986; Holland and Sutinen, 1999; Wilen et al., 2002). Most apply the methodology to recreational fisheries, but the last two describe applications to commercial sea fisheries. Owing to the origin of RUMs (see McFadden, 1974), their application is mostly found in the fisheries economics literature. To quote Wilen et al. (2002, p. 556), “economists believe that an advantage to using micromodels of individual behaviour that incorporate structure... is that they can predict responses to policies that have not been in place over the sample period used to estimate [the] response elasticities”. Hence, RUM analyses are particularly relevant for the consideration of proposed closed areas.

RUM results are often presented in aggregated form (i.e. aggregated predicted individual choices based on the significant explanatory variables that are the components of the utility), such as at a spatial level for all vessels. However, most other methods operate at the aggregated level. The disadvantage of aggregating data to measure behaviour is that factors are not included in the same detail as in the non-aggregated form. Key facets of RUMs are that they model discrete decisions, that no assumption of homogeneity among individuals is required, and as in most economics-based choice models, that utility drives individual choice with a deterministic and a stochastic error component (thereby generating the name “random utility model”).

Utility (Uij) is typically defined as a (linear) combination of a set of explanatory variables that together are surmised to form (for the most part) the non-random components of the utility (zij, the combination of explanatory variables, with coefficient β), and a stochastic error (random) component (εij):

\[ U_{ij} = \beta z_{ij} + \epsilon_{ij} \]

where, for a given person time-event, i (such as a fishing trip), choice j is made. The explanatory variables \( z_{ij} \) can consist of attributes of the choice, \( x_{ij} \), as well as characteristics of the individual, \( w_{i} \) (not included in this study). Through a choice of distribution of disturbances of the error term, typically logit, the model can be estimated. In the case of the conditional logit model (which we use here), the data set consists only of choice-specific attributes (\( x_{ij} \)).

The probability of a given choice being made can then be estimated from evaluating (and normalizing) the derived utility:

\[ \Pr(Y_i = j|x_{i1}, x_{i2}, ..., x_{in}) = \frac{e^{\beta x_{ij}}}{\sum_j e^{\beta x_{ij}}} \]

where \( Y_i \) is an indicator variable designating that choice j was made. The conditional logit (McFadden, 1974) has long been used for the estimation of these parameters. However, for spatial analyses, Wilen et al. (2002) state that conditional logit is inappropriate, because the independence of irrelevant alternatives (IIA) assumption it imposes could potentially be invalidated, and thus influence policy analyses that consider spatial aspects. IIA implies that a change in the choice set would not affect the relative choice probabilities, because the choices are assumed to be independent. To overcome this, Wilen et al. (2002) use the nested logit model (McFadden, 1981; Morey et al. 1993) which, although in basic structure is the same (but with the imposition of a hierarchical structure on the decision process), does not impose IIA to the same degree (see Greene, 2003). An alternative to the nested approach, which can be difficult to estimate for more than three or four hierarchical levels, is the mixed logit model, which similarly does not impose IIA, but can include choice attributes and individual characteristics (Train, 2003).

The English North Sea beam-trawl fleet operates out of the main east coast ports of England, generally in ICES Area IV, spending on average 250 days at sea (on typically 6-day trips). The main species targeted are plaice (Pleuronectes platessa) and sole (Solea solea), but cod (Gadus morhua) and other whitefish also contribute to the fleet’s earnings. The beam trawlers have an average length of about 37 m, an engine power of 1300 kW, and are operated by a crew of about 6.

Individual trip data for beam trawlers (English registered vessels only) were collated for 1999 and 2000 from the logbook fishing activity database. The year 2000 was taken as base year. Data from the previous year (1999) were used to obtain estimates for explanatory variables that have a one-year lag, using the assumption that past activity, catch, and catch rates may influence future decisions. The spatial coverage included ICES Statistical Areas IVa, IVb, and IVc.
in the North Sea. The spatial resolution was set at the size of an ICES statistical rectangle (e.g. 36F2), an area of about 30 × 30 nautical miles. There are approximately 200 rectangles in the North Sea. In effect, the exact number of rectangles in the RUM and simulation model depends on the choice of the resolution of the map, in terms of the sea—land divide. In other words, if a rectangle includes a small proportion of ocean, it can be designated as either land or sea, but rectangles where some fishing took place were designated as sea. However, owing to the discrete nature of RUM, only those rectangles that had more than ten trips during 2000 were included in the analysis. This reduction brought down the number of rectangles to a more manageable 52. The fishing hours covered by this subset constituted some 80% of the total activity of the fleet.

To start, a number of preliminary operations were performed on the data set. A few vessels did not include records for the physical explanatory variables (engine power, overall length), so their records were deleted. The data for individual trips included the catch and value for the species (or species groups) cod, haddock (Melanogrammus aegilfinus), whiting (Merlangius merlangus), Norway lobster (Nephrops norvegicus), lemon sole (Microstomus kitt), saithe (Pollachius virens), plaice, sole, skates and rays (Rajidae), redfish (Sebastes marinus), anglerfish (Lophius spp.), and turbot (Scophthalmus maximus). Individual trips for vessels that did not catch any of these species were deleted from the record. The number of vessels in the data set used for the analysis was 76, for which the total number of trips in the year 2000 was approximately 2500.

The explanatory variables included in the data set for completeness for the base year (2000) were trip length (days), effort (hours fishing), total value of the catch (£), total weight (value-weighted; kg), and value per unit effort (vpue, £ per hour). The variables were chosen to reflect past activity (length of trip and effort, and if significant, also habit), and some measure of benefit (catch or total value) or profit (total vpue). Value (total, or vpue) is used to take account of price differences between species within the mixed fishery. The one-year lag (1999) explanatory variables are effort (hours fishing), total value of the catch, total weight (value-weighted), and vpue, all in the same units as the corresponding variables in the base year. In the results, the activity of vessels in each rectangle is aggregated to year. Although this yields less detail, because it reduces the complexity of the model in terms of variables, it is the first step investigated in the ongoing nature of this analysis.

Simulation model of fishing effort

A simplified spatially structured simulation model was developed, utilizing the results of the RUM as the basis of its assumptions (see results in Table 1 later). The model simulates the effect of closing specific areas on the redistribution of fishing effort.

Note that effort, average trip length, and number of trips are directly (effort) or indirectly (average trip length and number of trips) intrinsic to the basic formulation of the simulation model. Therefore, only the previous year’s catch rate (vpue or cpue) can be used as a factor to influence decisions in the simulation model. There were no major differences between the results of the models based on vpue and on cpue, so cpue was used when the model was run under different scenarios.

The model simulates the effect (of closing areas on a fleet) on a vessel-by-vessel basis for each month, for each spatial unit (for example, ICES statistical rectangle), in the following series of steps.

(i) Each vessel’s effort distribution is computed from individual trip logbook data, to obtain the total effort (in h) per spatial unit per month per vessel (so a map can be obtained of each fishing vessel’s spatial distribution of fishing effort on a monthly basis). In addition, the aggregate effort of the fleet can be obtained by summing over all vessels.

(ii) Each vessel’s spatial distribution of catch rate is computed from individual trip logbook data to obtain the average catch rate (kg per h) per spatial unit per month per vessel, either for a previous (base) year, so reflecting the results of the RUM in this study, or by averaging over a specific past time period (the last five years), so a map can be obtained of each fishing vessel’s spatial distribution of catch rate on a monthly basis. Total catches for each species can also be computed and mapped.

(iii) Some spatial units are closed (assuming the closure occurs in the next year) and the total effort in all the closed areas for each vessel for each month is computed. This effort is the effort that is to be redistributed.

(iv) Based on the base-case model assumption that vessels will obtain the largest net benefits per trip if they fish in the spatial units with the highest catch rates, the effort is distributed in proportion to the average catch rate per spatial unit per month per vessel in the base year (of spatial units that are not closed).

(v) The redistributed effort is added to the total effort per spatial unit per month per vessel (only to spatial units that are not closed), and a predicted total effort per spatial unit per month per vessel is obtained.

The predicted effort (E’) in the following time period (t + 1) is

\[ E'_{t+1,v} = \frac{1}{\sum_{r=1}^{R} E_{t,v}} \left( \sum_{r=1}^{R} \frac{cpue_{t+1,v}}{cpue_{t,v}} \right) \]

given \[ \sum_{r=1}^{R} E'_{t+1,v} = \sum_{r=1}^{R} E_{t,v} \]
for a particular combination of spatial unit/rectangle \( r \), that is still open), time period \( t \), fishing unit \( v \), and closed area \( a \). Thus, the base-case model requires catch and effort data per spatial unit per time-step per fishing vessel, and the same data are used as in the RUM. If a vessel is confronted with the situation that, in a particular time period (e.g. one month), its fishing grounds are completely within a closed area, there are two options: (a) it returns to port, or (b) it allocates its effort to rectangles where it can fish. In this model, option (b) is assumed to be the case if an effort time-series indicates that there has been no significant reduction in effort during the closure of fishing grounds.

In the model, the assumption is that effort in year \( t + 1 \) is equal to that in year \( t \), which is a simplification at this stage, because no relationship between total effort and other explanatory variables (e.g. profit) has been included. In the case of the Dutch beam-trawl fleet, total effort dropped during 2001 when parts of the North Sea were closed, but effort was relatively stable in the English beam-trawl fleet (the case study for this research). In addition, cpue is assumed to be constant for each species over time, in each spatial unit, again a simplification because the model has not been linked to a spatial biological model.

The option exists to estimate the expected benefits of each spatial unit based on the historic patterns of profit for each spatial unit (instead of catch rates). The estimate of profit relies on detailed data on the fixed and variable costs of each operation, as well as on the port of landing for each trip. The average speed of trawling is required to compute the steaming and fishing costs. The base-case model therefore uses catch rate as a proxy for expected benefit, and this index is a measure of expected net benefits, although the distance to port has not been factored in at this stage.

Catch and effort data for individual trips of beam trawlers (English registered vessels only) were obtained for the period 1996–2001 from the logbook fishing activity database. The spatial coverage is the same as in the RUM (i.e. it includes ICES Statistical Areas IVa, IVb, and IVC in the North Sea). Similarly, the spatial resolution was set at the size of an ICES statistical rectangle. The total catch in each rectangle for every trip was computed along with the catch rate statistical rectangle. The total catch in each rectangle for a particular combination of spatial unit/rectangle \( r \), that was totally closed, but also of some that were partially closed. The model was set up with a monthly time-step, so it was not possible to model closure for half a month. The two months that were closed for the whole month were March and April. April was selected as base case, because it was the last full month of closure, and because it was thought it represented a period by which time the regulation had become well established.

The simulation model of fishing effort (as outlined above) was used to predict the redistribution of fishing effort (for 2001) of the beam-trawl fleet within two scenarios, using the following hypotheses:

1) vessels will rely on the previous year’s (i.e. 2000) catch rate (cpue) as a basis for their decisions, in terms of choice of location for rectangles left open;
2) vessels will rely on an average of their last five years (i.e. 1996–2000) of cpue as a basis for their decisions, in terms of choice of location for rectangles left open. If a vessel did not fish in one year, the information was still included in the average.

An example simulation was performed for April 2001 (based on data for April 2000), and the model results were compared with the observed April 2001 distribution for the English beam-trawl fleet, applying both of the above scenarios.\(^4\)

### Results

#### Location choice and the random utility model

The results of the RUM implementation of location choice using year 2000 data for English beam trawlers in the North Sea are presented in Table 1. The model and the variable coefficients are highly significant, at the 1% level. The positive signs suggest that the greater the value of the variables, the more effect there is on a given choice. The model developed is based on a conditional logit implementation; there are five choice variables for each rectangle included within the model.\(^5\)

The model is based on trips during the year to an ICES rectangle in the North Sea. In all, 52 rectangles, to which at least ten trips were made during 2000, are included in the

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\(^4\) In the RUM, 2000 was used as the base year, with 1999 as the base year \(-1\), whereas in the simulation model, predictions were made for 2001 (because that was the year when the area closure took place), and the year 2000 was used as the base year \(-1\). The reason for the difference is that it was not possible to run the RUM using data for 2001, because the area closure would have biased the results.

\(^5\) The variables shown in Table 1 are for the reduced model that best fitted the data. Many of the variables in the complete model were not significant, so were excluded from the analysis.
model. The total for the period is 576 trips. For the data collated for a given rectangle, AVTRIPLEN (days) is the average length of each trip that a vessel undertakes to a given rectangle in 2000, AVEFFORT is the effort (in h) deployed fishing over the period (one year in this case), and NO_TRIPS is the number of trips that a vessel made to that rectangle. Hence, the model can be specified with summed or average data for these variables. The rationale for selecting the average was that a skipper would, in part, make his decision on which rectangle to visit on the basis of the typical length of trip. For value and weight of catch, a combined variable is used (VALWGT), by applying a weighted index (catch weighted by value). The previous year’s (1999) cpue (measured here as vpue) was included through a binary variable FISH1999, that specified whether fishing took place in 1999, and VPUE1999, which gives the vpue that a given vessel obtained from the specified rectangle during 1999. For the censored data (i.e. other alternative trips to the one observed that the vessel could have made), simple averages were used over the year for all vessels.

In this simplified model, in terms of the estimated influence on the decision of which rectangle to visit, past experience seems to play an important role. The vpue of the vessel in 1999 in the same rectangle had a direct impact on the decision. The number of trips that a vessel made during the year to a given rectangle is also important in predicting another trip there. Further, a longer average trip (AVTRIPLEN), with more effort (AVEFFORT), also adds likelihood of a choice being made. In both cases, more past activity (number of trips, longer trips, more effort) in a location suggests a greater probability of returned activity.

In this model, the total weight or value of catch attained does not seem to have much influence on the decision of where to fish, with a coefficient of almost zero. In fact, the sign on this variable (VALWGT) is negative, suggesting that a higher value impacts negatively on the choice. This contrasts with reported results from other studies using similar methodology, such as those of Holland and Sutinen (1999, 2000), in which expected revenue does play a role in the decision-making process of where to fish. Nevertheless, the reason for this apparent anomaly possibly lies in the values calculated for this variable in the censored trips. Averages for all boats in a rectangle were used over the year, implying some homogenization of value/weight attainable in rectangles by a vessel. As discussed earlier, such an assumption implies that a skipper would have access to known catch potential in a rectangle where they had never fished before. Similarly, however, a zero catch in an area would be unlikely, owing to the skill and technology (such as fish finders) available to a skipper. Therefore, for this analysis, an averaging approach was used. This is an assumption similar to that made by Holland and Sutinen (2000), except that they used a translog production function to standardize effort before calculating expected revenue.

From the model, probabilities were calculated for each potential trip. With these values, the average effort applied in a rectangle was used to estimate the predicted distribution of effort in the rectangles included in the model. These results are presented in Figure 1a. On inspection, several rectangles were predicted to have had significantly more effort applied to them than observed in 2000 (Figure 1b). Such rectangles include 37F0 and 42F2, which in these example cases were coincidentally not included in the closed area that was implemented in 2001.

Simulation model of fishing effort

As an example using this model, a simulation was performed for April 2001, and the model results were compared with the observed April 2001 spatial distribution for the English beam-trawl fleet. The results for two scenarios in this simulation are shown in Figures 2 and 3.

The distribution of fishing effort for English beam trawlers in the North Sea in April 2000, which is used as the basis of the simulation, where vessels distribute effort based on cpue of the previous year, is shown in Figure 2a. The closed areas, presented as closed ICES rectangles in the simulation model of fishing effort, are also indicated on Figure 2b and c. In 2000 (Figure 2a), significant effort is expended in the area subsequently closed during April 2001. The model results for the predicted distribution of effort in April 2001 (Figure 2b), and the observed distribution of fishing effort for the same fleet in the same period (Figure 2c), can then be compared. At first glance, the predicted values appear to be associated in terms of magnitude and spatial distribution, but there is a westward shift in observed effort distribution (ICES rectangles 38F1 and 37F1 have predicted effort levels less than expected, and the model, scenario 1, does not predict effort to be distributed to ICES rectangles 39F0, 39E9, and 38E9).

The distribution of average fishing effort of English beam trawlers in the North Sea from 1996 to 2000, which is used as the basis of scenario 2, is depicted in Figure 3a. In this scenario, vessels distribute average effort on the basis of the

Table 1. English North Sea beam trawl RUM choice-specific variable and model coefficient estimates.

<table>
<thead>
<tr>
<th>Variable</th>
<th>β</th>
<th>s.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVTRIPLEN</td>
<td>0.05331*</td>
<td>0.019</td>
</tr>
<tr>
<td>AVEFFORT</td>
<td>0.02653*</td>
<td>0.002</td>
</tr>
<tr>
<td>NO_TRIPS</td>
<td>0.49045*</td>
<td>0.021</td>
</tr>
<tr>
<td>VALWGT</td>
<td>-0.00010*</td>
<td>0.000</td>
</tr>
<tr>
<td>FISH1999 • VPUE1999</td>
<td>0.01164*</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Significant at 1% level.
average cpue over the previous five years, and as such will only redistribute effort to an area where they had previously fished. If a vessel did not fish in a particular year, but had fished there before, the year it did not fish is included in the average. Similar to scenario 1, a comparison can then be made between the model results for the predicted distribution of effort in April 2001 (Figure 3b), and the observed distribution of fishing effort for the same fleet then (Figure 3c). Under this scenario, the magnitude of the values for predicted effort is greater than observed, so it cannot be used as absolute. The reason for both these effects is that the predicted distribution is based on a pattern with a longer history. Scenario 2 predicts effort being expended in areas farther west (38F1, 39F1, and 38E9), so there is a stronger association with the observed effort. However the real overall distribution is more dispersed. The correlation (r) between observed and predicted values was calculated as a measure of fit; it was 0.59 and 0.63 for scenarios 1 and 2, respectively. The scenario predictions are significantly better than predictions from a uniform distribution of effort (p < 0.001), using either a standard test of the correlation coefficient (d.f. = 55; Snedecor and Cochran, 1967), or a test modified to take account of the spatial correlation in the observed and predicted values (scenario 1, d.f. = 44.0; scenario 2, d.f. = 44.2; Dutilleul, 1993). There appears to be a trade-off between the two scenarios from a methodological perspective. If several years of data are used as a basis for the calculations, then a more homogeneous distribution of effort is obtained. However, under this scenario, areas will be included that, although not fished the previous year, appear as regular fishing areas interannually.

Discussion

The results of the RUM analysis show some of the assumptions that could be expected a priori for location choice, and therefore they are used to form the foundation of the assumptions and decision rules in the simulation model. Principally, some previous knowledge or experience (such as a high catch rate) of a given rectangle may have some bearing on the decision to fish in a given area. The RUM analysis only includes choice-specific variables (i.e. factors that vary for alternative decisions), and it is solved using a conditional logit model. With development, a nested logit model, or perhaps a mixed logit model, may be more applicable to the analysis, especially if considering a spatially related future policy of closed areas (Wilen et al., 2002). In such cases, the inclusion of individual-specific factors, such as boat characteristics, is also possible. In the example presented, distance to fishing grounds may be a key factor that could be included, and it may add significantly to the prediction capability of the model.

Overall, the results of the simulation model of fishing effort for scenario 2 seem to be more consistent with the observed spatial distribution than the results for scenario 1 (for the example provided). There are two possible reasons for this: either effort shifted farther west because fishing grounds in the west are closer to port, or the fishing vessels were basing their decisions on the expected catch rates, that in turn depend on the average historic catch rate (1996–2000) of the fleet on the grounds. Vignaux (1996),

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6 The test was run using software provided by Legendre (2000). Available at http://www.fas.umontreal.ca/BIOL/legendre/.
however, found no evidence that there was enough information transfer for vessels to make decisions on the basis of catch rates of the other vessels of the fleet. Therefore, for the future we propose exploring distance to port or to distribute them to other spatial units, on the basis of catch rates of the other vessels of the fleet. Furthermore, we will explore the possibility of using satellite data to map fishing effort may be developed to include landing port and economic data (such as prices and fixed and variable costs). If vessels fish only in areas that have been closed (during a particular month), the option exists to return vessels to port or to distribute them to other spatial units, on the basis of economic data (such as prices and fixed and variable costs).

Figure 2. The results of the simulation model of fishing effort: (a) distribution of fishing effort of English beam trawlers in the North Sea in April 2000, which is used as the basis of scenario 1 (vessels distribute effort on the basis of the cpue of the previous year); (b) model results for the predicted distribution of effort in April 2001; (c) observed distribution of fishing effort for the same fleet in April 2001.

Figure 3. The results of the simulation model of fishing effort: (a) average distribution of fishing effort of English beam trawlers in the North Sea from 1996 to 2000, which is used as the basis of scenario 2 (vessels distribute average effort on the basis of the cpue over the previous 5 years); (b) model results for the predicted distribution of effort in April 2001; (c) observed distribution of fishing effort for the same fleet in April 2001.
of areas fished in other months, or to areas fished by other vessels. In the current form of the model, it is possible to distribute a vessel’s effort to areas on the basis of the spatial distribution of the fleet, but it is not possible in the current model to account for competitive interactions.

The model was originally developed to predict fishing effort distribution in terms of its impact on benthos (Hutton et al., 2002). The aim was to model closed areas and to use the model to predict where effort would be redistributed. The results could then be used as input to other studies that might estimate the impact of the increased effort on benthos in the remaining open areas. The model can also be used to estimate the impact on fish stocks (as in the assessments undertaken to support the recent recovery programmes; see also Horwood et al., 1998), if effort and catch data are available for all fleets that target a particular species. Therefore, the model could link to a spatial biological model of the distribution of stocks (as proposed by Hilborn and Walters, 1987); the task of undertaking such an analysis could be supplemented by models of migration developed from remote tagging studies in a specific area, such as the North Sea. These models might form the basis of a spatial bioeconomic model of mixed fisheries, where the model can also be used to estimate the economic impact of closed areas on a fishing fleet(s).

The overall approach of testing alternative explanatory variables within a RUM, then applying those that are significant in a simulation model, provides a sensible set of methodological procedures for spatial analysis, using location choice rather than basing the simulation model on some ad hoc belief about behaviour. The potential of both approaches to investigate the beam-trawl fishery and the temporary closed area of the North Sea is encouraging.

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